SAFETY EVALUATION REPORT

Request for Change to Certificate of Compliance USA/9976/AF (DOE), Rev. 0 to Add Steel to Drums for Low Enriched Uranium Oxide Shipments

Docket No: 06-31-9976

Prepared by: _____ Date: 9/14/6

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INTRODUCTION

The Savannah River Operations Office of the Department of Energy (DOE) has submitted a request for change to the Certificate of Compliance (CoC) USA/9976/AF (DOE), Rev. 0, in order to meet the Nevada Test Site (NTS) Waste Acceptance Criteria for the shipment of 227 drums containing low-enrichment uranium oxide (LEUO).[1] Steel shots, up to 50 lbs, will be added to each of approximately two-thirds of the 227 IP-1 drums.

The original approval for CoC USA/9976/AF(DOE), Rev. 0 was documented in the Packaging Certification Approval Record under Docket 04-10-0000. The DOE had originally requested the Department of Transportation (DOT) to issue an exemption from certain fissile regulations in order to permit the shipment of uranium oxide powder with U^{235} enrichment up to 1.098 wt.% in 227 IP-1 drums meeting DOT Specification 7A Type A performance requirements. The exemption demonstrated the criticality safety of proposed shipping campaign with specified exclusive use shipment controls. There are no containment or shielding issues associated with the contents.

At the request of DOT, the Nuclear Regulatory Commission reviewed DOE's exemption application and confirmed the criticality safety of the proposed shipments. However, DOT subsequently advised DOE that an exemption was not required, insofar as sufficient documentation has been provided to justify DOE certifying the drums as Type AF containers. The contents approved for USA/9976/AF (DOE), Rev. 0 do not include steel in any of the 227 drums.

The technical basis for the material change of adding steel to drums is provided in the *Savannah River Site Request for Department of Transportation Exemption (U)*, WSRC Document No. OBU-TRA-2004-00022, Rev. 2, June 8, 2006.[2] The Revision 2 changes involved mainly Attachment 6 of OBU-TRA-2004-00022, Rev. 1 that included additional calculations showing no adverse effects to criticality safety during transportation due to the addition of steel to drums. This Safety Evaluation Report (SER) contains the review and confirmatory evaluation of the technical basis document in Ref. 2.

TECHNICAL EVALUATION

1. Spherical safe mass values for the LEUO material

For a given amount of fissile material, the most reactive configuration is one that achieves optimal moderation, minimizes leakage, and attains full reflection of neutrons emitted from the fissile material, e.g., U^{235}, for sustaining chain reactions. A UO_3/H_2O mixture in spherical geometry with water surrounding the sphere is generally considered as the most reactive configuration that can be achieved at a certain intermediate ratio (H/U) of the moderator content in the mixture.

Monte Carlo calculations were performed using the MCNP-4C code to obtain the safe spherical mass of LEUO and the results are given in Attachment 4 of Ref. 2. MCNP-4C is a general-purpose Monte Carlo radiation transport code developed and maintained by the Los Alamos National Laboratory and used widely by members of the criticality safety community. UO_3/H_2O mixtures in a spherical geometry surrounded by 30-cm water were modeled in the MCNP-4C calculations with the water content in the mixtures varying from 0 to 40 wt.% (to determine the optimum moderation), and with U^{235} enrichments of 1.098, 1.084, 1.05, and 1.033 wt%. The criticality safety criterion used is a k_{safe} value of 0.934 such that the calculated $k_{eff} + 2\sigma \leq k_{safe}$, where k_{eff} is the effective neutron multiplication factor and σ is the standard deviation associated with the statistical uncertainty of the MCNP-4C calculations. Table 1 below lists the values of the spherical safe mass thus obtained for configurations with optimum

moderation and full reflection. No neutron poison, e.g., boron, or absorber material, e.g., steel, were included in these MCNP-4C calculations.

Table 1. MCNP-4C calculated spherical safe mass for UO_3/H_2O mixtures with optimum moderation and full reflection by water

U^{235} enrichment (wt.%)	1.033	1.050	1.084	1.098
Spherical safe mass (metric tons, MT)	4.50	4.06	3.07	2.81

An equation has been derived to fit the MCNP-4C calculated spherical safe mass as follows:

$$UO_3 \text{ Mass (MT)} = -26.698 \text{ (wt.\% } U^{235}) + 32.076$$

This equation was used to calculate the values of the safe mass for the 20 shipping groups listed in Attachment 1 of Ref. 2. Each shipping group consists of multiple number of drums, each containing LEUO with maximum U^{235} enrichments between 1.033 and 1.098 wt.%.

EM-60 Evaluation - The spherical safe mass values in Table 1 for UO_3/H_2O mixtures are bounded by the results of independent calculations documented in Ref. 3 for UO_2-H_2O homogeneous mixtures; the extra oxygen atom in UO_3 is not expected to have any significant effect on the criticality calculations. The use of a criticality safety criterion, $k_{safe} = 0.934$, is more conservative than the usual k_{safe} value of 0.95 with a safety margin of 5%. The assumption of a UO_3/H_2O mixture in spherical geometry with optimum moderation and full reflection is the most conservative case, and, therefore, the limits placed on the number of LEUO drums in the shipment plan (Attachment 1 of Ref. 2), to be discussed later under criticality safety index determination, should increase the margin on criticality safety even for the worst-case hypothetical accident.

2. Criticality analysis for arrays of UO_3 drums

10 CFR 71.59 defines standards for arrays of fissile material packages that are applicable to the LEUO drums. Part (a) of 71.59 states "... the designer of a fissile material package shall derive a number N based on all of the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water:

(1) Five times N undamaged packages with nothing between the packages would be subcritical;

(2) Two times N damaged packages, if each package were subjected to the tests specified in 71.73 (Hypothetical accident conditions) would be subcritical with optimum interspersed hydrogenous moderation; and

(3) The value of N cannot be less than 0.5."

Criticality calculations were performed for arrays of UO_3 drums using the MCNP-4C code and the details of the models and results are given in Attachment 6 of Ref. 2. Two 3-D array configurations were modeled, one with five rows of 24 drums in each row and arranged with a triangular pitch (4-5-6-5-4), for a total of 120 drums; and the other a 5 x 5 x 5 square-pitch array for a total of 125 drums. The total number of drums in either configuration bounds the "5N" undamaged packages that vary from 40 to 65, i.e., 8 to 13 drums, in each of the twenty LEUO shipment groups described in Attachment 1 of Ref. 2.

In all of the array calculations, each drum was modeled as a cylinder (55.88-cm ID x 83.82-cm internal height) with wall, top and bottom treated as 16-gauge (0.1519-cm thickness) carbon steel. Each drum

was assumed to contain 803 lb of UO_3 with a maximum U^{235} enrichment of 1.098 wt.%, and with 3 to 24 wt.% H_2O. No neutron poison, e.g., boron, or absorber material, e.g., additional steel shots, were included in the MCNP-4C calculations. The fissile solution in each drum was modeled as a cylinder filled with LEUO materials inside the internal radius of the drum; other parameters considered in the 3-D array models included the gap, i.e., surface-to-surface separation (0, 2, 4 cm) between drums, interstitial water density (0, 10, 20, and 100 wt.%), and full reflection on all sides of the arrays by water. The criticality safety criterion, $k_{eff} + 2\sigma \leq k_{safe}$, where $k_{safe} = 0.934$ and k_{eff} and σ are from the MCNP-4C calculations for the arrays, is the same as that used for the determination of the spherical safe mass in Attachment 4 of Ref. 2.

The calculated k_{eff} values for the two most reactive configurations are 0.931 ($\sigma = 0.0005$) for the triangular-pitch array of 120 drums, and 0.923 ($\sigma = 0.0005$) for the square-pitch array of 125 drums. The triangular-pitch configuration has 15 wt.% H_2O in the UO_3/H_2O mixture inside each drum and 10% interstitial moderation between drums. The square-pitch configuration has 18 wt.% H_2O in the UO_3/H_2O mixture inside each drum and no interstitial moderation between drums. In both configurations, the calculated values of $k_{eff} + 2\sigma$ are less than the conservative $k_{safe} = 0.934$.

EM-60 Evaluation – MCNP-X, a more current version of MCNP than MCNP-4C, was used to perform confirmatory calculations of the two most reactive configurations of arrays identified in Attachment 6 of Ref. 2. Table 2 shows the comparison of the MCNP calculations. The k_{eff} values obtained by EM-60 differ slightly from those in Attachment 6, Ref. 2. The values of $k_{eff} + 2\sigma$ are, however, all lower than k_{safe} of 0.934, with an adequate margin on criticality safety.

Table 2. Comparison of MCNP calculations for the most reactive configurations of arrays of drums

Configuration	Evaluation	H_2O (mixture / interstitial, wt.%)	Gap (cm)	$k_{eff}(\sigma)$	$k_{eff} + 2\sigma$
Triangular pitch	Ref. 2	(15 / 10)	0	0.931 (0.0005)	0.932
	EM-60	(15 / 10)	0	0.93266 (0.00018)	0.93335
Square pitch	Ref. 2	(18 / 0)	0	0.923 (0.0005)	0.924
	EM-60	(18 / 0)	0	0.91720 (0.00067)	0.91788

3. Criticality Safety Index determination

The critical safety index (CSI) for each of the 20 groups of shipments was calculated based on the mass limit, i.e., spherical safe mass, and 10 CFR 71.59(a)(2). For example, the CSI of Shipping Group 1 in Attachment 1, Ref. 2 is determined as follows: The 2N damaged drums is calculated by dividing the spherical safe mass (6089 lbs), which depends on the U^{235} enrichment, by the average drum weight (757 lbs) of the eight drums in this shipping group. This gives N = 4.02, and CSI = 50/N = 12.44 (rounded up to 12.5). For exclusive use shipment and according to 10 CFR 71.59(c)(2), the sum of CSI shall be less than 100, hence the number of drums permitted is 100/CSI = 100/12.5 = 8.04 (rounded down to 8). The values of CSI and the permitted number of drums for the other shipping groups in Attachment 1, Ref. 2 were determined in a similar manner; they are tabulated in Table 3, along with the mass limits for each shipping group.

Table 3. Mass limits, CSI and number of drums permitted in shipment groups 1 to 20

Shipping Group	Maximum U^{235} enrichment (wt. %)	Mass Limit (lbs)	Criticality Safety Index	Number of Drums (exclusive use)
1	1.098	6089	12.5	8
2	1.066	7973	9.6	10
3	1.063	8150	9.4	10
4	1.062	8209	9.3	10
5	1.060	8326	8.9	11
6	1.059	8385	9.1	11
7	1.055	8621	8.8	11
8	1.053	8738	8.7	11
9	1.089	6089	12.5	8
10	1.050	8915	8.5	11
11	1.048	9033	8.2	12
12	1.046	9151	8.3	12
13	1.043	9327	8.2	12
14	1.037	9680	8.0	12
15	1.034	9857	7.7	13
16	1.031	9916	7.7	13
17	1.026	9916	7.7	13
18	1.017	9916	7.7	13
19	1.010	9916	7.7	13
20	1.003	9916	7.7	13

EM-60 Evaluation

The mass limits, CSI and the permitted number of drums in the 20 shipping groups in Table 3 are confirmed by the EM-60 review staff.

4. Reactivity change due to adding steel shots (up to 50 lbs) to drums

The MCNP calculations performed for the spherical safe mass determination and for the most reactive array configurations did not include neutron poison, e.g., boron, or absorber material, e.g., steel shots, as part of the contents in the drums. Adding steel shots to the drums is expected to decrease the reactivity of the system (individual drum and array of drums) due to parasitic neutron absorption. This was demonstrated in the MCNP calculations for which 42 and 50 lbs of steel were modeled as a fictitious lid and added to each drum of the two most reactive configurations of arrays identified in Attachment 6, Ref. 2. The calculated values of $k_{eff} + 2\sigma$ are 0.91932 and 0.91746, respectively, which represent a reduction of 1.31% and 1.51% of the corresponding values of $k_{eff} + 2\sigma$, without the addition of steel.

5. Type A packaging shipping requirements

Item 4 Conditions in USA/9976/AF (DOE) states that "*This certificate is conditional upon the fulfilling of the applicable Operational and Quality Assurance requirements of 49 CFR parts 100-199 and 10 CFR*

Part 71, and the conditions specified in Item 5 below." The packaging requirements for fissile materials in 10 CFR 71.55 and 71.59 have been evaluated and shown satisfactory per Sections 1 to 4 of this TRR. All other requirements for fissile material shipments in Type A packagings such as shipping papers, marking, labeling, and placarding in 49 CFR 172.203(d), 172.310, 172.403, and 172.500, respectively, must also be met. Attachment 5A of Ref. 2 documented the compliance of the LEUO 55-gallon IP-1 drums to the regulatory requirements in 49 CFR 173.24 *General Requirements for packagings and packages*; 173.24a *Additional general requirements for non-bulk packagings and packages*; and 173.411(b) for *Industrial packagings* (IP)-1 drums. The specific requirement in 49 CFR 173.24a(b)(2) for non-bulk packaging filling limits is met by the restriction that the gross mass shall not exceed the 900 lbs capacity of the IP-1 package.

Attachment 5B of Ref. 2 contains closing instructions for the LEUO 55-gallon IP-1 drums after the previously closed drums are opened for addition of steel shots. Attachment 8B establishes the acceptance criteria for drum integrity. Any drum that does not meet the acceptance criteria shall be overpacked in an 85-gallon drum meeting DOT 7A Type A requirements and shipped accordingly.

It should be noted that Attachment 8A, Ref. 2 Instructions for compliance with alternative packaging requirements of 49 CFR 107.105(c)(9) is related to an application for exemption, not for certification of a Type AF packaging. Attachment 8A, ref. 2, however, contains other relevant information for the IP-1 drums on quality assurance controls, package design, manufacture, performance test criteria, in-service performance, and service-life limitations. The in-service performance section of Attachment 8A, Ref. 2 is where the NTS waste disposal criterion is mentioned, i.e., up to 50 pounds of steel shot be placed into approximately 2/3s of the drums (on top of the LEUO).

EM-60 Evaluation

The attachments in Ref. 2 that are related to the Type A packaging shipping requirements and IP-2 drums are reviewed and found acceptable.

SUMMARY / CONCLUSION

The technical basis document (Ref. 2) has been reviewed to determine the safety adequacy for the request for change to CoC USA/9976/AF (DOE), Rev. 0 to add steel to drums for low enriched uranium oxide shipments. Based on EM-60's confirmatory evaluation, there is an adequate margin and reasonable assurance of criticality safety during transportation for each of the 20 shipping groups identified in Table 3 of this TRR. The mass limits of LEUO and the number of drums permitted under exclusive use shipment for the shipping groups were determined very conservatively based on the spherical safe mass and 10 CFR 71.59(a)(2). The requirement in 10 CFR 71.59(a)(1) is also satisfied by the MCNP-4C criticality calculations shown in Table 2 of this TRR. These MCNP calculations assumed no neutron poison, e.g., boron, nor absorber material, e.g., steel shots inside the drums. Adding steel shots to the drums is expected to reduce the reactivity due to parasitic neutron absorption, which was confirmed for two of the most reactive array configurations identified in Attachment 6, Ref. 2. Adding steel shots to drums, therefore, will further increase the criticality safety margin for the shipments.

The technical basis document (Ref. 2) has demonstrated that the drums would satisfy the requirements of 10 CFR 71.55(e). If the drums were subjected to the hypothetical accident conditions in 10 CFR 71.73 (drop and fire), it is anticipated that the drums would breach and the LEUO contents dispersed, rather than conglomerate, into a sphere with optimum moderation and full reflection. The technical basis document (Ref. 2) has also demonstrated that all other requirements for fissile material shipments in Type A packagings and IP-1 drums in 49 CFR 172 and 173 are met.

References

1. DOE memorandum, D. Gillas, SRO to Dr. James M. Shuler, EM-60, June 22, 2006, "Low Enriched Uranium Oxide."

2. *Savannah River Site Request for Department of Transportation Exemption (U)*, WSRC Document No. OBU-TRA-2004-00022, Rev. 2, June 8, 2006.

3. NUREG/CR-0095 and ORNL/NUEG/CSD-6, "Nuclear Safety Guide/TID-7016/Revision 2," June 1978.